(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 227 614**
A2

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **86830376.9**

(22) Date of filing: **16.12.86**

(51) Int. Cl.[4]: **G 01 S 13/90**

(30) Priority: **24.12.85 IT 4898385**

(43) Date of publication of application: **01.07.87 Bulletin 87/27**

(84) Designated Contracting States: **DE FR GB NL SE**

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(54) **Signal processor for synthetic aperture radars, particularly suitable for parallel computation.**

(57) This invention concerns a synthetic aperture radar system within which focussing processing is achieved through the use of filter banks. based upon undersampling and polyphase networks.
The focussing operation consists of the correlation of the datum with system response to a point scatterer.

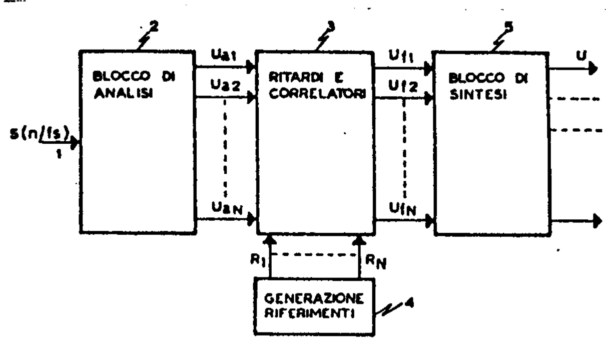

FIG. 1

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Description

"SIGNAL PROCESSOR FOR SYNTHETIC APERTURE RADARS, PARTICULARLY SUITABLE FOR PARALLEL COMPUTATION"

The invention concerns a synthetic aperture radar system within which the focussing is achieved through use of filter banks, based upon undersampling and poliphase networks.

The radar echo, in its in-phase and quadrature components, is split into N complex signals through bank of N adjacent band pass filters. These signals are shifted to band base and undersampled.

Operating in parallel, it is possible to correlate each of these signals with the corresponding reference signal.

This can be achieved, in turn, in a simple and adaptive manner, based upon data related to the relative movement between sensor and target. The different correlator outputs provide focussed images, but have poor resolution. Such signals can be combined to provide an image having the maximum possible resolution with a technique similar to that used for its splitting.

It's to be appreciated that the combining of low resolution images may be made so as to obtain images of higher resolution, yet lower than the maximum possible, so that through their power addition, a better signal to noise ratio is achieved at the cost of a very limited additional implementation effort.

The advantages above are such as to justify the adoption of a similar structure, non limited to azimuth focussing, but extended to radial pulse compression which has, till now, been achieved through analogue techniques.

Technical background of the invention

Focussing of SAR (Synthetic Aperture Radar) images is generally made, at first, in the radial direction (pulse compression) with analogue techniques and later in the azimuth direction using digital techniques or using optical techniques. Digital techniques are preferable due to their flexibility.

Focussing consists in the datum correlation with system response to a point scatterer. This is approximatily made up of a linearly frequency modulated sinus wave.

It is to be appreciated that the frequency modulation isn't perfectly linear, and that neither the pulse response is localized at constant reflection time, due to the radial migration effect (D.A. Austerman, A Kosmo, H.M. Jones, E. Poggio. "Development in Radar Imaging" IEE Trans. on Aerospace and Electr. Systems AES-20, n. 4, July 1984). Image focussing requires therefore the convolution of bidimensional matrix data (azimuth and range) using a bidimensional filter, the pulse response of which may extend, in the case of satellite sensors, to up to a thousand samples.

A technique which can be used is that of bidimensional numeric convolution by means of a filter having finite length pulse response, possibly implemented using discrete Fast Fourier Transforms. The drawback is that this technique is not all flexible and it does not lend itself to echo radial migration correction, nor to system parameter variation due to sensor motion irregularities.

The foremost technique known today is that of step transform with respect to which the technique proposed with this patent is a net improvement (M. Dack, M.R. Ito, I.G. Cunning. "Application of Efficient linear F.M. Matched Fellenng Algorithmsto Synthetic Aperture Radar Processing" IEE Proc. Vol. 13297, No 1, Feb. 1985).

The step transform technique consists in the conversion of the incoming signal, radially compressed into a frequency chirp having limited time duration T, repeated in time.

If the slope of such chirp is equal but opposite to that of the incoming signal, this is transformed by a constant frequency chirp, into a sequence of sinus signals at piecemeal constant frequency (staircase).

This signal is examined spectrally using techniques which are based upon discrete Fourier transforms.

The amplitude and frequency progression lead to the location of the single scatterer and to an estimate od its reflection coefficient.

This technique, in a rather simple manner, as a first approximation, takes into account both radial migration and small linearity deviations of the frequency modulation law (K.H. Wu, M.R. Vant - "Extension to the Step Transform SAR Processing Technique" IEE Trans. Aerospace an Aerospace and Electr. System, Vol. AES-21 No. 3, May 1985). At any rate, the main drawback which affects this technique is its block structure, which impedes easy adaption.

Furthermore, precise linear F.M. deviation correction isn't possible without reducing the processing advantages which would be obtained otherwise.

The technique of radar echo splitting into band limited signals with adjacent bands is known, but is rarely adopted due to its high computing costs when implemented using traditional techniques.

Polyphase networks for signal splitting are known, but have never been applied to synthetic Aperture radars.

The present invention will now be described with reference to one of its presently preferred implementations, which is reported for sake of illustration, but is not limited to this, with reference to the figures of the drawings attached, where:

Figure 1 shows the proposed circuit general layout;

Figure 2 shows the shape of the filter bank response, which is useful to explain the functioning of the structure of figure 1:

Figure 3 shows in detail the structure of the circuit layout in accordance with the invention.

With reference to the drawings, the circuit presented in this invention, implements the radar echo focussing in three successive steps according to the schematic shown in figure 1.

The complex radar echo 1 (in phase and in quadrature components) sampled at frequency fS. is sent to an analysis block 2. which performs the following:

- filtering of signal 1 through N band pass filters with identical transfer function. but centered around equispaced frequencies fi (see figure 2):
- base band traslation of each filter output. so that the centre frequency of the pass band (fi) corresponds to zero frequency;
- undersampling of each signal after base band traslation.

Thus the N U_{ai} complex signals sampled at a frequency fS/N are obtained at the output of the analysis block 2. These signals are sent to the block where each signal U_{ai} is delayed by a suitable number of sampling steps, correlated with a reference signal Ri, related to the corresponding frequency band. Reference signals Ri are obtained at block 4, conceptually, by carrying out the same set of operation as block 2, on a signal which represents the response of the radar signal to a point scatterer. Reference Ri can be obtained by beating such response to a point scatterer with an exp complex sinus waveform (j2 fit) at zero frequency, with band pass similar to that of the filters contained in block 2. Such references can be easily computed once the sensor target motion is known.

Outputs U_{fi} are already focussed signals, but with limited resolution, N times lower than the theoretical maximum possible.

Block 5 combines the focussed signals at low resolution at output of block 3 so that only one signal at full geometric resolution, or M signals at M times lesser resolution than the maximum theoretical one, are obtained. It is therefore possible to obtain a full range of geometric resolutions. which stretch from the maximum obtainable from the system up to that of the single signal at block 3 output.

Block 5 carries out the inverse operation to that of block 2. lining up in frequency the outputs of contiguous channels till the desired resolution is obtained.

It is to be noted that in the case a geometrical resolution M times lesser that the maximum is required. M signals. obtained focussing the radar echo on different frequency bands, are available. By carrying out a non coherent sum (sum of complex signal modules) we can improve the signal to noise ratio of the total output by a factor close to M.

The qualifying aspect of the proposed circuit solution is that the analysis operations in block 2 (therefore. with inverse procedure. also those of synthesis in block 5) immediately perform an undersampling of the radar echo without first undergoing numerical filtering.

The innovation is in the application of such techniques to the processing of radar signals.

With reference to figure 3. we can see that the circuit schematic is such that the complex radar echo (in phase and quadrature components) sampled and quantized. 1. is sent to a switch 2A which sorts out the complex samples at the input toward the N numeric filters having finite pulse response of bank 2C.

The N outputs of these filters are the inputs to block 2C where they are combined so that the N block outputs are the discrete Fourier transforms of the inputs.

The signals at the input to the different filters of bank 2C are therefore made up of complex signal 1, which is gradually time shifted by a sampling step and undersampled by a factor N. The responses to the discrete impulse of the N filters are obtained starting from the response to the discrete pulse with a number of coefficients equal to a multiple of N of a generating filter having transfer function of the low pass type with cutoff frequency fS/2N.

The process through which we get filter coefficients still consists of time traslations and undersampling by a factor N. Obtained this way, outputs of block 2C correspond exactly to those suggested for block 2 of figure 1 - (M. Bellanger - "Digital Processing of Signals: theory and Practise Wiley) - (P. Crochiere and L. Robiner "Multirate Digital Signal Processing Prentice Hall").

To develop a bank of partially overlapping filters, we shall have to insert a zero between two successive samples sent to each filter and its pulse response can be obtained from that of the generating filter of undersampling at an N/2 rate.

The outputs of block 2C are therefore signal 1 filtered by one of the filters of the bank at figure 1 converted to base band and undersampled.

A battery of correlators 3b correlates each of these signals with the suitable reference signal. Each of these reference signals consists of the total reference (system response in presence of a point scatterer) pass band filtered with a filter which has a band equal to that of the filter with which we have obtained the signal to correlate against the reference in subject.

The different reference signals will be different than zero only due to the limited number of samples, but they will be mutually delayed. Delays 3a compensate for such delays, limiting to the minimum the length of the correlation. Outputs 6. which are the result of the N correlations, provide N focussed signals having resolution which is N times lesser than the maximum possible (sub-look). The various sub-looks can be combined coherently using a structure similar to that used for analysis, and this is made up of:

- block 5A which calculates the discrete Fourier transform of the N signals 6;
- N finite pulse response filters 5B:
- switch 5C which scans the N outputs from the filters obtaining a sampling signal fS equal to that of the input signal.

This way we obtain a signal which is focussed with the maximum space resolution possible.

However we may also obtain a full range of intermediate reductions through slight modifications to the synthesis structure.

It suffices to make block 5A calculate M discrete Fourier transforms on a number N/M of consecutive outputs 6.

The filters remain the same, but delay ib(B) must be modified. This way we have M signals having a resolution which is M times lesser than the theoretical maximum.

Processing gain

Processing gain is due to the fact that references R_1, as well as having a narrower band than the overall reference, and therefore can be sampled at a lower frequency, also have a shorter duration. This is such that each single reference signal is made up of a non nil number of samples which is considerably lower (up to N 2 times lower, in theory) than required to describe the overall reference.

Correction of the radial migration

Radial migration can be compensated by combining the output of analogue channels of different range bins with suitable weights which differ from channel to channel.

Channels are those consisting of each of the bank filters shown in Figure 1 and successive operations performed on the related filtered signal.

Uniqueness

The qualifying aspects of the whole system are its simplicity and complete adaptability to variations and difformities of the frequency modulation law of the radar echo.

Such adaptability can be achieved with the maximum circulation of parameters, making the presented invention's circuit layout particularly suitable for large scale integration implementation technology.

The invention has been described with reference to one of its presently preferred implementations, which has been reported as an illustration, but is not limited to this, based upon description above and on the drawings attached.

Claims

1. Synthetic Aperture Radar Signal Processor, which is particularly suitable for parallel calculation, characterized by the fact that it includes means for the processing connected to focussing which includes banks of filters based upon undersampling and polyphase networks, the layout being such that the focussing operation consists in datum correlation with system response to a point scatterer.

2. Signal Processor, as per claim 1, which is characterized by including means to compensate for variations and anomalies affecting the frequency modulation of the radar echo which include means for insertion of variations to the delays and mods to the reference signals.

3. Radar signal processors according to claims 1 and/or 2, characterized by the fact that layout is such that a variable geometric resolution is possible without loss of radiometric resolution.

4. Synthetic Aperture Radar Signal Processor, which is particularly suitable for parallel processing according to one or more of the claims above and, substantially, as shown and described with reference to the figures attached.

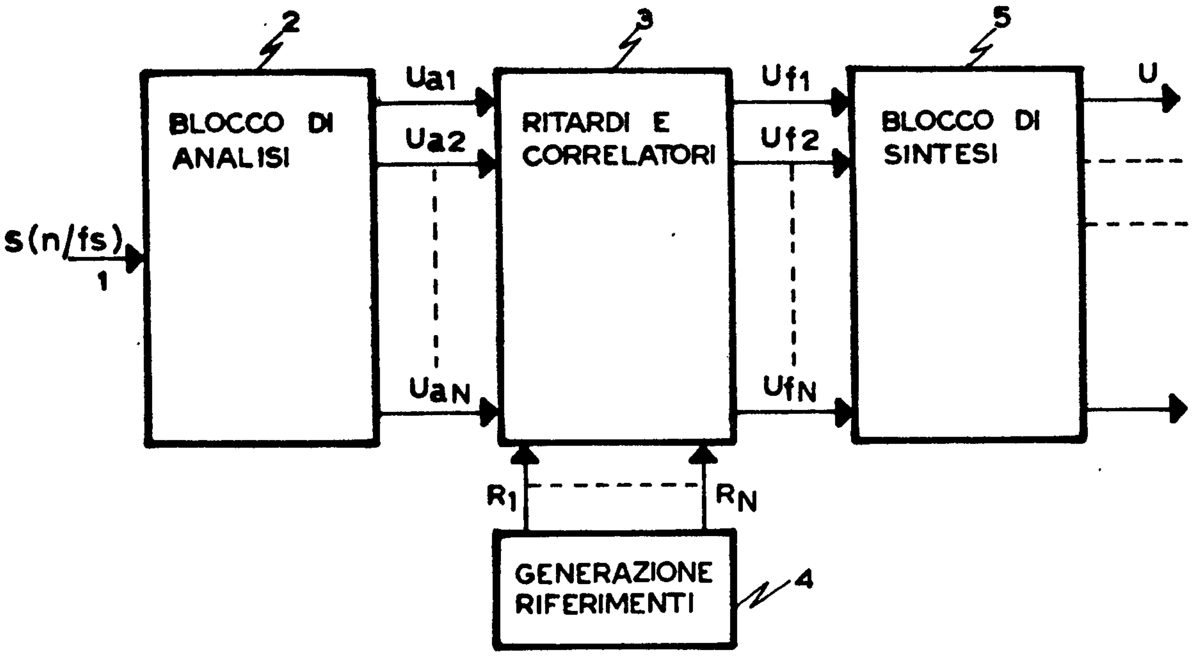
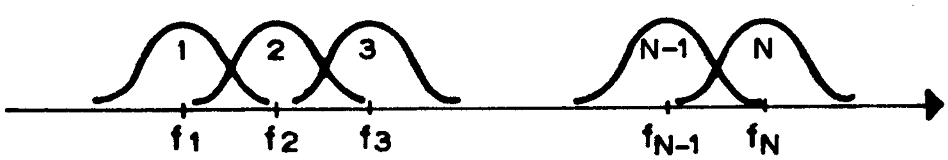


FIG. 1



$f_i - f_{i-1}$ = COSTANTE

FIG. 2

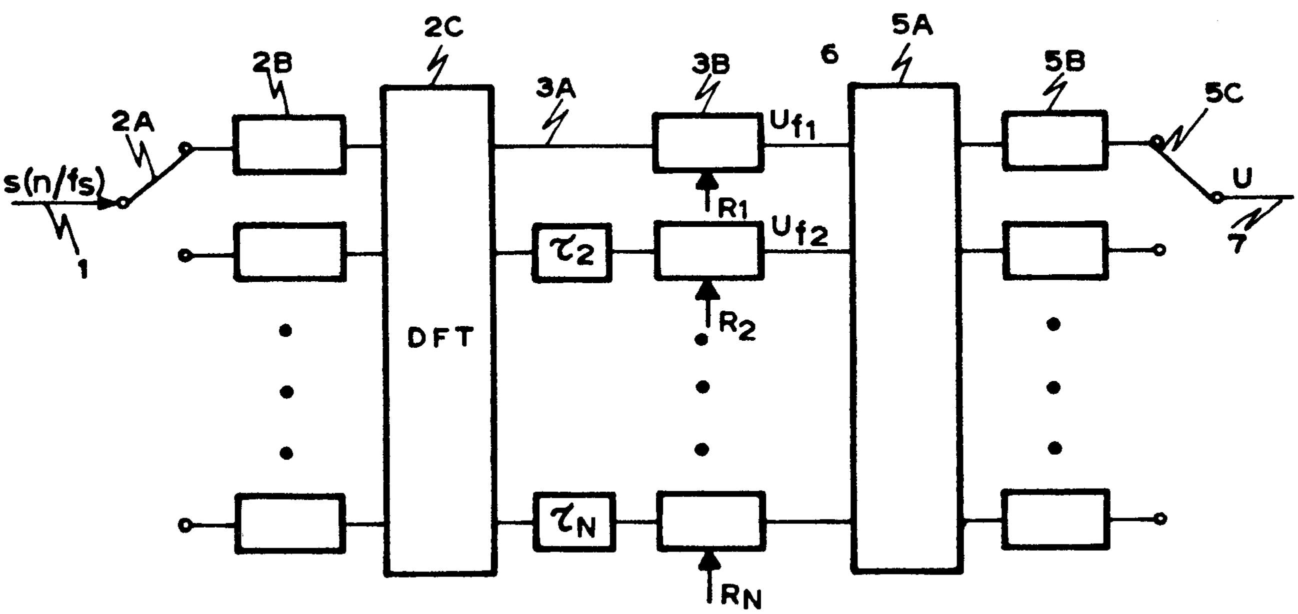


FIG. 3